Claims

What is claimed is:

1. A fuel injector comprising:

an injector body having an upper portion and a lower portion;

a pressure intensifier movably positioned in said upper portion;

a flow control valve attached to said upper portion;

a direct control needle valve positioned in said lower portion;

an electrical actuator attached to said lower portion; and

a three-way needle control valve positioned in said lower portion and operably coupled to said electrical actuator, and including a valve member trapped between a low pressure seat and a high pressure seat, and including a low pressure passage disposed therein that includes a flow restriction relative to a flow area past said low pressure seat.

2. The fuel injector of claim 1 wherein said upper portion includes a surface with an actuation fluid inlet therethrough.

3. The fuel injector of claim 1 wherein said injector body defines an actuation fluid inlet and a fuel inlet.

4. The fuel injector of claim 1 wherein said electrical actuator is a first electrical actuator; and including

a second electrical actuator operably coupled to said flow control valve; and

said flow control valve includes a spool valve member.

5. The fuel injector of claim 4 wherein said second electrical actuator includes an armature attached to said spool valve member.

6. The fuel injector of claim 4 wherein said flow control valve includes a pilot valve member; and

said second electrical actuator includes an armature attached to said pilot valve member.

7. The fuel injector of claim 1 including a pair of electrical conductors with a portion exposed outside said upper portion and being electrically connected to said electrical actuator via a electrical socket connection at least partially located inside said injector body.

8. The fuel injector of claim 1 wherein said pressure intensifier includes a free floating plunger.

9. The fuel injector of claim 8 wherein said plunger is symmetrical about three orthogonal axes.

10. The fuel injector of claim 1 wherein said injector body includes an unobstructed vent passage disposed therein and extending between a piston return cavity and an outside of said injector body.

11. The fuel injector of claim 1 wherein said needle control valve includes a high pressure passage disposed therein that includes a flow restriction relative to a flow area past said high pressure seat.

12. The fuel injector of claim 1 wherein said pressure intensifier and said direct control needle valve are free of dynamic seals.

13. A fuel injection system comprising:

a plurality of fuel pressurization assemblies and direct control nozzle assemblies;

a pressure intensifier movably positioned in each said fuel pressurization assembly;

a flow control valve attached to each said fuel pressurization assembly;

a common rail fluidly connected to each said fuel pressurization assembly;

an electrical actuator attached to each said direct control nozzle assembly; and

a three-way needle control valve positioned in each said direct control nozzle assembly and operably coupled to said electrical actuator, and including a valve member trapped between a low pressure seat and a high pressure seat, and including a low pressure passage disposed therein that includes a flow restriction relative to a flow area past said low pressure seat.

14. The system of claim 13 including a source of low pressure fuel;

said common rail contains a medium pressure actuation fluid; and

each said fuel pressurization assembly defining an actuation fluid inlet fluidly connected to said common rail, and a fuel inlet fluidly connected to said source of low pressure fuel.

15. The system of claim 13 wherein each said fuel pressurization assembly is attached to a direct control nozzle assembly as a unit fuel injector.

16. The system of claim 13 wherein each said fuel pressurization assembly includes a surface with an actuation fluid inlet therethrough.

17. The system of claim 13 wherein said fuel pressurization assembly defines an actuation fluid inlet and a fuel inlet.

18. The system of claim 13 wherein said electrical actuator is a first electrical actuator; and includes

a second electrical actuator operably coupled to said flow control valve; and

said flow control valve includes a spool valve member.

19. The system of claim 18 wherein said second electrical actuator includes an armature attached to said spool valve member.

20. The system of claim 13 wherein said flow control valve includes a pilot valve member; and

said second electrical actuator includes an armature attached to said pilot valve member.

21. The system of claim 13 including a pair of electrical conductors electrically connected to said electrical actuator via a electrical socket connection located at least partially inside said direct control nozzle assembly.

22. The system of claim 13 wherein said pressure intensifier includes a free floating plunger.

23. The system of claim 22 wherein said plunger is symmetrical about three orthogonal axes.

24. The system of claim 13 wherein said fuel pressurization assembly includes an unobstructed vent passage disposed therein and extending

between a piston return cavity and an outside of said fuel pressurization assembly.

25. The system of claim 13 wherein said fuel pressurization assembly and said direct control nozzle assembly are free of dynamic seals.

26. A method of injecting fuel, comprising the steps of:

positioning a needle control valve in a first position that fluidly connects a needle control chamber to a fuel pressurization chamber and fluidly blocks said needle control chamber to a low pressure passage;

increasing fuel pressure within said fuel pressurization chamber at least in part by moving a flow control valve to a first position;

moving a needle control valve to a second position that fluidly connects said needle control chamber to a low pressure passage and fluidly blocks said needle control chamber to said fuel pressurization chamber at least in part by supplying electrical energy to a direct control nozzle assembly;

restricting fluid flow from said needle control chamber to the low pressure passage relative to a flow area past a low pressure seat; and

decreasing fuel pressure within said fuel pressurization chamber at least in part by moving said flow control valve to a second position.

27. The method of claim 26 including a step of leaking less than 50 cubic millimeters of fuel from said direct control nozzle assembly per injection event.

28. The method of claim 26 wherein said increasing step includes supplying actuation fluid through a surface of a fuel pressurization assembly.

29. The method of claim 26 including a step of supplying fuel and an actuation fluid to separate inlets of a fuel pressurization assembly.

30. The method of claim 29 wherein said increasing fuel pressure step includes a step of supplying electrical energy to a fuel pressurization assembly.

31. The method of claim 26 including a step of retracting an intensifier piston at least in part by applying a spring force; and

retracting a plunger at least in part by applying a hydraulic force.

32. The method of claim 26 including a step of venting a volume underneath an intensifier piston to outside a fuel pressurization assembly.

33. The method of claim 26 wherein the steps are performed in a number and sequence that produces up to five discreet injections per cylinder per engine cycle.

34. The method of claim 26 wherein the steps are performed in a number and sequence that produces a main injection accompanied by at least one of a pilot injection and a post injection with a dwell less than 500 micro seconds.

35. The method of claim 34 wherein said main injection includes at least one of a boot, a ramp and a square rate shape.

36. The method of claim 34 wherein said pilot injection has a volume less than or equal to about 10 cubic millimeters, and said post injection has a volume of about 15 cubic millimeters.